QRS Detection Algorithm Using Savitzky-Golay Filter

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***Abstract*: QRS part of an electrocardiogram (ECG) is physiologically important for cardiac disease detection and extraction of this waveform from the raw signal is an important part of ECG analysis. Pan Tompkins' algorithm of QRS detection is an established method for extraction of this part of ECG. In this paper, a modification has been done on Pan Tompkins' algorithm by using a Savitzky-Golay filter in place of the high pass filter and differentiator of Pan Tompkins' algorithm. Then QRS detection of normal as well as diseased ECG has been done using both Pan Tompkins' algorithm and the modified algorithm developed in this work for comparison.**

***Index Terms*- electrocardiogram, QRS, Pan Tompkins' algorithm, Savitzky-Golay filter**

I. Introduction

Processing and extraction of features from ECG is of importance for doctors as many physical conditions and diseases can be detected using this signal as well as for engineers who obtain ECG by different stimuli and subject it to various algorithms to obtain information. Also in case of ECG it is easy to obtain the signal from the human subject as it is non-invasive as well as no drugs or radiations are required. Cardiologists usually use the time-domain ECG signals which are recorded on strip-charts to analyze ECG signals. For diagnosis purposes, the parts of the waveforms present in normal ECGs and their corresponding occurrences in the cardiac system are important.

The ECG wave consists of certain parts named as the P wave, PR interval, QRS complex, ST segment, T wave, QT interval and then the infrequent presence of U wave. The sino- atrial node or the SA node is positioned on the left atrium and this initiates the electrical signal causing atrial depolarisation. Although the atrium is anatomically divided into two parts, electrically they function as one part.
Atria have very little muscle and produce a wave of small amplitude called the P wave. The PR segment is the subsequent part after the P wave and occurs as the electrical impulse is conducted through the atrio-ventricular node or the AV node, bundle of His and Purkinje fibres. The PR interval can be defined as the time between the onset of atrial depolarisation and the onset of ventricular depolarisation. After the PR interval, QRS complex occurs. This complex is generated by the depolarisation wave which travels through the interventricular septum via the bundle of His and bundle branches and reaches the ventricular myocardium via the Purkinje fibre network. The impulse first depolarises the left side of the septum, and then spreads towards the right. The left ventricle has larger muscle mass and thus its depolarisation dominates the ECG wave. The QRS complex ends at the J point and from here starts the ST segment. The ST segment which lies between the J point and the onset of the T wave, represents the period between the end of ventricular depolarisation and repolarisation. The T wave is the result of ventricular repolarisation. This wave in a normal ECG is asymmetrical as the first part of this wave is more gradual than the subsequent part. The QT interval is measured from the beginning of the QRS complex to the end of the T wave. Measurement of this interval is done by taking into account the heart rate as this interval elongates as heart rate decreases. The last part of the ECG is the U wave which is found just after the T wave ends. It is a small deflection and generally upright [1-2].

In this paper, the disease that has been taken is known as ventricular tachyarrhythmia and the data is obtained from PhysioNet. Filtering of the signals has been done on ten data named cu01 to cu10 [11]. The raw data available in Physionet were passed through an active second order low-pass Bessel filter of cut-off frequency 70 Hz before digitization, and were digitised at 250 Hz with 12-bit resolution over a 10 V range (10 mV nominal relative to the unamplified signals). Each data is approximately 8.5 minutes in duration. These data show the presence of sustained ventricular tachycardia, ventricular flutter and ventricular fibrillation [11].

Ventricular fibrillation is a serious condition of the heart which may lead to stoppage of the heart if untreated. Precursor of fibrillation is often ventricular tachycardia or flutter. So it is important to detect flutter and tachycardia in the ECG. Ventricular tachycardia is defined as three or more ventricular extrasystoles in succession at a rate of more than 120 beats per minute. The tachycardia may be self terminating but is described as "sustained" if it lasts longer than 30 seconds [2]. This kind of tachycardia falls under broad category tachycardia which maybe of ventricular or supraventricular in origin but is mostly ventricular. In ventricular tachycardia the sequence of cardiac activation is altered, and the impulse no longer follows the normal

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intraventricular conduction pathway. As a consequence, the morphology of the QRS complex is bizarre, and the duration of the complex is prolonged [2]. The ECG waveform which is obtained is overshadowed with noise signal due to which essential features cannot be identified from it. There are many algorithms present for denoising an ECG signal and popular among them is the Pan- Tompkins' algorithm [3,9]. In this algorithm feature extraction is restricted to QRS detection from the original signal by passing the signal through a band pass filter and a differentiator and then squaring of the resulting signal. The band pass filter is the one which eliminates noise and the differentiator is used to provide information about the slope of the QRS complex. Squaring of the signal is done so that all negative values in the waveform are changed to positive values. This process is a nonlinear operation which amplifies the output of the differentiator nonlinearly. Then the signal is passed through a moving integrator to obtain the QRS waves [3,9].

This paper shows an alternative way of QRS detection from the ECG signal using Savitzky-Golay filter in place of the band pass filter of the Pan Tompkins' algorithm. A normal as well as a diseased ECG data showing ventricular tachyarrythmic ECG data are taken and Pan Tompkins' algorithm using Savitzky-Golay filter is implemented. The respective QRS detected signals have been obtained from both types of data.

II. Theory

A. Pan Tompkins' Algorithm

i) Band pass filter

The band pass filter that has been used has been done by using a low pass filter and then a high pass filter in cascade. The purpose low pass filter is to suppress high frequency noise [9]. Filter design using digital filters having integer coefficients allows real time processing speeds. No floating point processing required so speed is high. This band pass filter for QRS detection algorithm reduces noise in the ECG signal by matching the spectrum of average QRS complex, eliminating noise due to muscle artefacts, 60 Hz power line interference, baseline wandering and T wave interference. QRS energy is maximised by the pass band of approximately in the 5 to 15 Hz range. The filter is an integer filter which has poles located such so as to cancel out the zeroes [9]. The second order low pass filter has the transfer function of as shown in equation (1).

$$H(z)= (1- z^{-6})^2/(1- z^{-1})^2 \quad (1)$$

The cut- off frequency of the filter is 11 Hz, delay is 5 samples and the gain is 36 [9]. The difference equation of the filter is as shown in equation (2).

$$y(nT)= 2y(nT- T) - y(nT - 2T) + x(nT) – 2x(nT – 6T) + x(nT – 12T) \quad (2)$$

The high pass filter is implemented by subtracting a first order low pass filter from an all pass filter with delay [9]. The transfer function of the low pass filter is as shown in equation (3).

$$Hlp(z)= Y(z)/X(z)= (1 – z^{-32})/(1 – z^{-1}) \quad (3)$$

The transfer function of the high pass filter is as shown in equation (4).

$$Hhp(z)= P(z)/X(z)= z^{-16} – Hlp(z)/32 \quad (4)$$

It is finally obtained as in equation (5).

$$Hhp(z)= (-z^{32} + 32z^{16} – 32z^{15} + 1)/(32z^{32} – 32z^{31}) \quad (5)$$

The difference equation of the filter is as in equation (6).

$$p(nT)= x(nT – 16T) – 0.0313[y(nT – T) + x(nT) – x(nT – 32T)] \quad (6)$$

The low cut off frequency of the filter is about 5 Hz and delay is 80 ms. The gain of this filter is 1 [9].

ii) Derivative

To provide information about the slope of the QRS complex, differentiation of the signal is done, after it has been through the band pass filter [9]. A five point derivative is implemented using the transfer function as shown in equation (7).

$$H(z)= 0.1(2 + z^{-1} – z^{-3} – 2z^{-4}) \quad (7)$$

The difference equation for this transfer function is as shown in equation (8).

$$y(nT)= (1/8)*[2x(nT) + x(nT – T) – x(nT – 3T) – 2x(nT – 4T) \quad (8)$$

The fraction 1/8 in equation (8) is an approximation of the actual gain of 0.1. This derivative approximates the ideal derivative in the dc through 30 Hz frequency range, and it has a filter delay of 10 ms [9].

iii) Squaring

Now, the signal is to be squared. This is the non linear processing of the signal. It is done to get all positive values so that later these values can be processed to get the corresponding squared waves. Also this processing emphasizes the higher frequencies of the ECG signal which are due to the presence of the QRS complexes [9]. Point by point squaring of the signal obtained from the differentiator is implemented by equation (9).

$$y(nT)= [x(nT)]2 \quad (9)$$

iv) Moving Integrator

The slope of the R wave is not the absolute way to detect QRS complexes in an ECG. There may be many long duration and large amplitude QRS waves in the ECG which is abnormal. Only slope of R wave cannot detect these waves [9]. So a moving window integrator is used so that these waves can be detected as well. The difference equation for this moving window integrator is as shown in equation (10).

$$y(nT)= (1/N) [(x(nT) – (N-1)T) + (x(nT) – (N-2)T) +\ldots+x(nT)] \quad (10)$$

It is important to choose an appropriate value for N, which is the number of samples in the width of the moving window [9].

B. Savitzky-Golay Filter

Savitzky-Golay filter has been used both for ECG noise reduction and compression [4-8]. It has been used because of its signal following capabilities by least squares approach [8,10]. The Savitzky-Golay filter that has been used in this paper is of zero order and of frame length 41.

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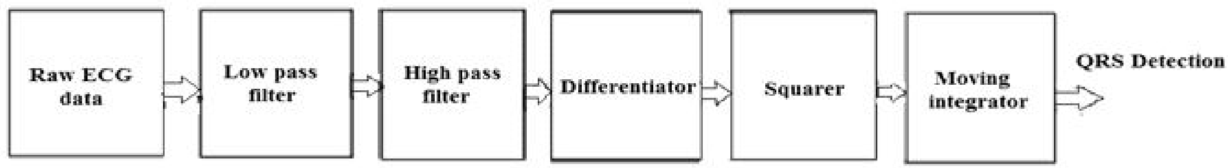

Fig 1: Block diagram showing Pan Tompkins' algorithm of QRS detection

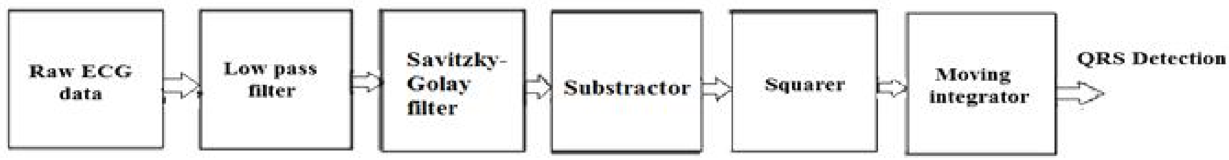

Fig 2: Block diagram showing QRS detection using Savitzky-Golay filter

III. Procedure

On both the normal and diseased data, Pan Tompkins' algorithm has been implemented using the conventional algorithm and then using Savitzky-Golay filter in place of the high pass filter and differentiator. The block diagrams of these two methods are shown in Fig. 1 and Fig.2 respectively.

IV. Results

The established Pan Tomkins' algorithm as shown in Fig. 1 has been applied on normal and ventricular tachyarrythmic ECG data and the final QRS detected signals obtained are shown in Fig. 3 and Fig. 5 respectively. The results obtained after applying the developed algorithm using Savitzky-Golay filter is shown in Fig. 4 and Fig. 6 for normal and diseased ECG data respectively. The different blocks of the algorithm have applied as shown in Fig. 2 and the final QRS detected signals are obtained.

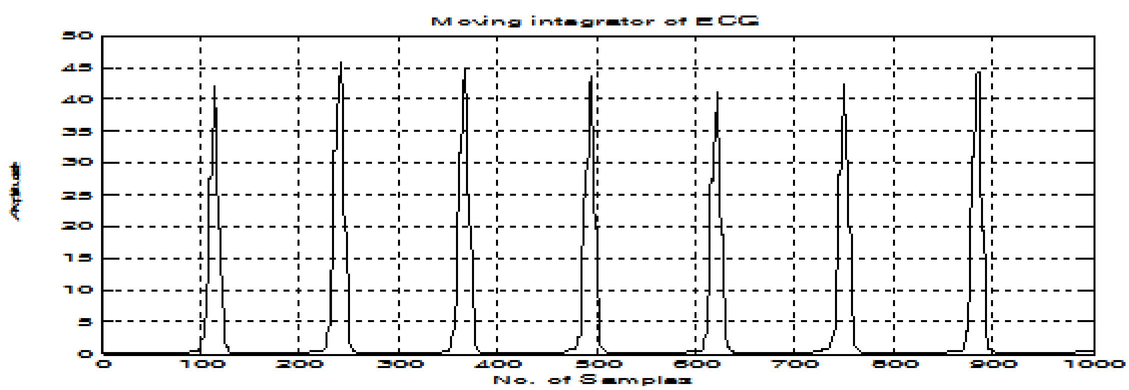

Fig. 3: Result of the last block of Pan Tompkins' algorithm for normal ECG data

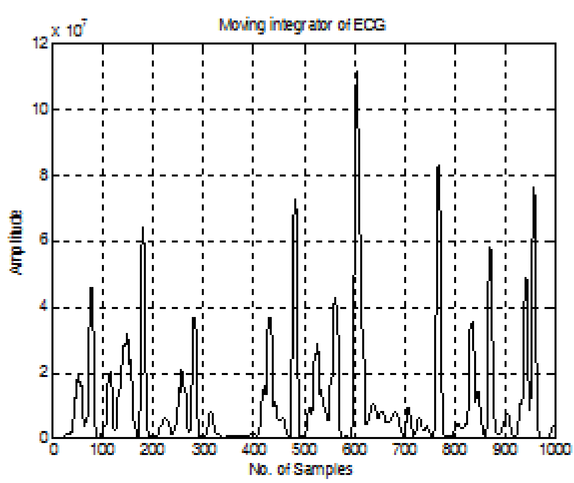

Fig. 4: Result of the last block of Pan Tompkins' algorithm for diseased ECG (data cu04)

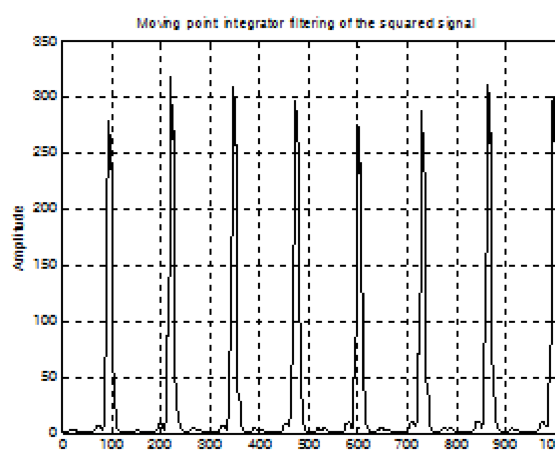

Fig. 5: Result of the last block of Pan Tompkins' algorithm with Savitzky-Golay filter for normal ECG data

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V. Conclusion

From the results obtained using the developed algorithm, it can be observed that QRS detection is possible with higher amplitudes of the detected QRS peaks. This algorithm also eliminates the need of the high pass filter and the differentiator blocks as present in Pan Tompkins' algorithm.

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